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The Retinal Size of a Familiar Object as a Determiner of Apparent Distance[1]

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I. Introduction

The present study is concerned with the retinal size of a familiar object as a cue to distance. A distinction is sometimes made between apparent absolute distance and apparent relative distance. Apparent absolute distance is the apparent distance of an object from the observer. Apparent relative distance is the apparent depth between objects without reference to the position of the observer. The characteristic which discriminates between these two types of apparent distance is the reference point or point of zero distance with respect to which the perception occurs. If this reference point involves the apparent position of the observer, an absolute-distance perception has occurred. If this reference point is independent of the apparent position of the observer and only involves objects external to the observer, relative-distance perception is involved.

One of the factors which is considered to be a cue to the perception of absolute distance is the retinal size of familiar objects. For a constant physical size, the retinal (angular) size of an object decreases with increasing distance from the observer. Familiarity with a certain physical size of an object at various distances might result in a distance being perceptually ascribed to each retinal size of the familiar object. When the observer is presented with a familiar visual object of a particular retinal extent, the perception might be that the object is at a particular distance, with this perceived distance being related to the retinal size of the object (5, 6). This will be called the *size-distance hypothesis*. According to this viewpoint, a familiar visual stimulus of a particular retinal size will be seen at the distance position which a normal-sized object of the same familiar category would have to occupy in order to have the particular retinal size. Within limits, if the retinal size doubles, the perceived distance should halve; if the retinal size is halved, the perceived distance should double, etc. It is a problem of this study to investigate whether the retinal subtense of a familiar object can act as a determiner of the apparent absolute distance of that object from the observer.

If two similar familiar objects of different retinal size are presented simultaneously, the one with the smaller retinal subtense may appear to be more distant than the other. This might occur even though neither object is perceived as being at any particular absolute distance. In this case, the perceived-distance difference of the two objects would involve a relative- not an absolute-distance perception. If the two objects were presented successively, the same results might occur and the same interpretation be applied to these results. In the case of successive presentation, the memory of the retinal extent of the first object could be compared with that of the second object. With either the simultaneous or successive presentation of objects, relative retinal size might result in a per-

[1] The authors wish to thank Kay Inaba, Robert E. Page, and John J. Cox for their help in collecting and analyzing the data.

[2] The opinions or conclusions contained in the present report are those of the authors. They are not to be construed as reflecting the views or endorsement of the Department of the Army.

ceived relative distance. *In investigating whether the retinal subtense of a familiar object is an effective cue to its absolute distance, the relative-size cue must not be available between objects presented in the test situation.* This indicates two requirements for determining the relationship between familiar retinal subtense and perceived absolute distance: *(a)* a test situation must be used in which only *one object* is presented visually to the subject; and *(b)* the different retinal subtenses of the familiar object must be presented to different subjects.

The problem of determining whether an absolute- or a relative-distance perception (or both) are involved in a particular distance perception is difficult. Pertinent to this problem is a consideration of the response by which the distance perception is measured. The first requirement, stated at the close of the preceding paragraph, for finding the relation between the retinal subtense of a familiar object and perceived absolute distance suggests that a nonvisual method of measuring perceived absolute distance be used. In the present study a motor performance was employed. The subject was asked to throw darts to the distance of an object without being able to see the results of the throw. This task would ordinarily require that the subject judge the distance of the object from himself. However, even the results of this task must be interpreted with caution. If, for example, an object appears indefinitely located in distance, a subject, when given the task of throwing to the distance of this object, may make some throwing response. If, subsequently, an object is presented which appears to be less distant than the first object, the subject may throw to a lesser distance. This may occur even though both the first and the second object are perceptually indefinitely located in their distance from the subject. In this case, the difference between the throwing to the two successively presented objects would indicate the perceptual depth between them. The change in the throwing scores could be considered a measure of relative and not of absolute distance perception. Consequently, for any subject, only the throwing to the object which is *first* presented may be considered in measuring the perceived absolute distance of that object. This is in agreement with the second requirement stated previously.

The experimental evidence for the occurrence of relative- and absolute-distance perception as a function of retinal size has been reviewed by Ittelson (3). Several studies have seemed to indicate that the retinal size of a familiar object is a cue to its absolute distance. Hastorf (1) had subjects adjust the size of a monocularly observed object until it appeared to be equidistant with a post in a binocularly observed field. He found that the adjusted size of the monocular object differed directly as a function of its assumed physical size, in order for it to appear at the same distance position as the post. He also found that the apparent distance position of the monocular object with respect to the post changed as its assumed size was changed. Ittelson and Ames (4) were interested in determining the effect of apparent distance upon accommodation and convergence. The apparent distance of a playing card was measured by adjusting a movable post to the perceived distance of the card. The retinal size of the playing card was varied by the experimenters. It was found that, for the same physical distance of the playing card, the adjusted position of the post varied inversely with the retinal subtense of the playing card. Ittelson (3) had subjects adjust a movable package of cigarettes or a checkerboard design to the apparent distance position previously occupied by an experimental object. In one experiment two sizes of playing cards, ink blots, and diamond-shaped figures were used as experimental objects. The assumed size and physical distance of the experimental object was kept constant while its retinal size was varied. In a second experiment using playing cards, a typewritten letter, and a match box as experimental objects, either or both assumed size and retinal size were varied with physical distance held constant. In both experiments, when familiar experimental objects were employed, the movable object was adjusted,

in general, to a distance position which a normal-sized object of the same kind as the experimental object would have to occupy, in order to have the same retinal subtense as the experimental object.

The results of these three studies seem to indicate that the retinal size of a familiar object can determine its apparent absolute distance. But, in none of these studies has the possibility been eliminated that the perception which was measured was a perception of relative, not absolute, distance. The method of measuring perceived absolute distance involved an apparent distance judgment between an experimental object and another object (a comparison object) with both objects visually presented. In the experimental field the only cue to distance was the retinal size of the experimental object. *The comparison object was presented in a generally well-structured comparison field. Regardless of whether the experimental and comparison objects were presented simultaneously or successively, this method permitted relative-size judgments to be used in making the distance judgment.*

Consider the case in which a familiar object was present in both the experimental and comparison field. For example, in one part of the study by Ittelson (3), a package of cigarettes in the comparison field was adjusted to the apparent distance position previously occupied by a 1½-size playing card in the experimental field. The resulting distance adjustment of the package of cigarettes was to a distance which was approximately two-thirds of the physical distance of the playing card (3, p. 63). This result can be explained by assuming that the subject adjusted the distance of the cigarettes until a ratio of the retinal size of the cigarette package and playing card was reached which was that normally experienced by the subject when ordinary objects of these types were at the same distance from himself. If this explanation is correct, the perception of absolute distance was not involved in the adjustment.

Consider the case in which a nonfamiliar object was used in the comparison field with a familiar object in the experimental field. For example, in the study by Ittelson and Ames (4) the comparison object was a movable post and the experimental object was a playing card. The study by Hastorf (1) also is an example of this case. The assumption of the observer that the experimental object was, for example, a ping-pong ball made the experimental object a familiar object. To the extent that the comparison field was sufficiently well-structured to provide information as to the physical size of the post, a relative size judgment between the post and the familiar experimental object could be used in adjusting the post and experimental object to apparent equidistance.

These three studies do not meet the first requirement given previously for testing the relation between size and perceived absolute distance. The second requirement was also not met, in that the same subjects were used in more than one test situation. Subject comparisons of the retinal sizes of experimental objects between subsequent test situations may be expected to result in the perception of relative distance. That this will occur even when the experimental objects are not familiar is suggested by the results which Ittelson obtained when ink blots and diamond-shaped figures were used as experimental objects. The apparent distance of the experimental object, as determined by the apparent equidistance adjustment of the comparison object, was less for the larger than for the smaller experimental object of similar shape (3, p. 63). The adjustment of the comparison object in the initial situation would be to an indifferent distance. The adjustments of the comparison object in subsequent situations, involving an experimental object of the same shape but different size, would be inversely related to the size change of the experimental object.

II. Apparatus and Procedure

In the present study, the throwing of darts was used to measure the perceived distance of an object in situations in which, ideally, *only the retinal size of a familiar object was present as a possible cue to distance.* From the experimental result of thrown distance, perceived distance was to be inferred. For this reason, it was considered desirable to specify the magnitude of the throwing response as a function of the perceived distance. This was experimentally determined by using situations in which a variety of cues to distance were available. These situations are called "full-cue situations." The situations in which it was attempted to eliminate all cues to depth but that of retinal subtense are called "reduced-cue situations." It is assumed that in the full-cue situations the distance of the object from the observer was correctly perceived. Any difference in the full-cue situations between the physical and the thrown distance was attributed to a lack of one-to-one correspondence between visually per-

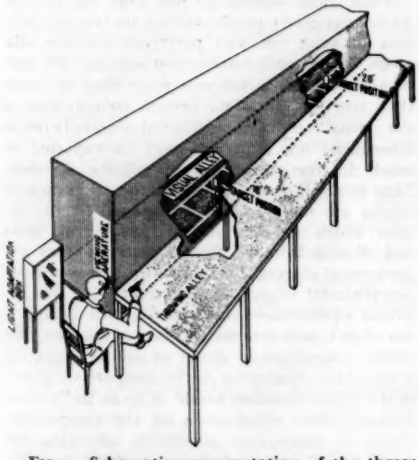

FIG. 1. Schematic representation of the throwing and visual alley for the full-cue situations.

ceived distance and thrown distance, and not to any inaccuracy in the perceived distance. The relation between thrown and visually perceived distance, which was experimentally determined from the full-cue situations, was used to convert thrown distance to perceived distance in the reduced-cue situations.

A. *The Reduced-Cue Situations*

1. *Apparatus*

The experimental situations of this study were presented in a visual alley separated from an adjacent throwing alley by a partition of dark cloth. Figure 1, which illustrates the full-cue situations, can also be used to discuss the reduced-cue situations. Both the visual and throwing alley were 4 feet wide and 40 feet long. A small rectangular aperture (1 inch by 5 inches), located 15 inches above the surface of the visual alley and at the same height as the surface of the throwing alley, allowed the subject to see into the visual alley. The surfaces of the visual alley and the surface containing the viewing aperture were dark. The ladder pattern shown on the floor of the visual alley in Fig. 1 was present only in the full-cue situations.

The familiar object used in the reduced-cue situations was produced by seven-of-spades photographic transparent positives. One transparency was of a normal-sized card (2-¼ inches by 3-½ inches) and the other was of a double-sized card (4-½ inches by 7 inches). Each of the two transparencies was fitted on the face of a light box and transilluminated with white light. No light from the box was visible except that passing through the transparency. When viewed in an otherwise dark room, a lighted transparency appeared to be an illuminated playing card and will be referred to as a playing card throughout this study. When a playing card was presented in the visual alley, the bottom of the card was at the height of the floor of the throwing alley.

Only one card was present in any one situation. Four reduced-cue situations were used. These will be designated by letter as follows:

A—A double-sized card at 10 feet.
B—A normal-sized card at 10 feet.
C—A double-sized card at 20 feet.
D—A normal-sized card at 20 feet.

Considerable care was taken with the reduced-cue situations so that no part of the visual alley or any object except the single playing card was visible to the subject when he looked through the viewing aperture. Black baffles were placed in the visual alley so that light from the playing card which fell on the floor and walls of the alley would not be visible. As an additional precaution, the subject was light-adapted before looking through the viewing aperture. The light-adapting surface (see Fig. 1) had a brightness of 11 foot-lamberts. The brightness of each playing card was 1.1 foot-lamberts.

The cloth partition between the visual and throwing alley prevented the subjects from seeing where the thrown darts landed. This was necessary since, if the thrown darts had landed in the field of view, relative-distance judgments between the card and dart could have occurred. The darts used in the throwing were 6 inches long and weighed approximately 11 grams. The distance to which the darts were thrown in the throwing alley was measured to the nearest centimeter.

2. *Procedure*

Eighty men who were right-handed and had at least 20/20 corrected vision in their right eyes were used as subjects. Prior to being subjects, these men were not informed of the purpose of the experiment. In the reduced-cue situations the viewing was monocular with the left eye of the subject covered. Before looking into the visual alley, the subject was given 20 practice throws to accustom himself to the throwing task. The throwing alley was lighted for this purpose. Following this, all lights except that from the adaptation surface and playing card were turned off. A shutter covered the viewing aperture. A mark on this shutter allowed the subject to orient his head so that his eye would be in the correct viewing position when the shutter was raised. The subject viewed the adaptation surface for approximately five seconds, after which he oriented his head with respect to the shutter mark and the adaptation surface was turned off. The shutter was raised and the subject looked at the playing card. By questioning, it was ascertained that the subject saw the stimulus as a seven-of-spades playing card. The subject was reminded of his task which was to throw a dart so that it landed at the distance of the playing card. He was also reminded that the height of the bottom of the card was the same as that of the floor of the throwing alley. The subject was handed a dart, which he threw down the throwing alley. The shutter was then closed, the adaptation light turned on, and the subject again light-adapted. This procedure of light-adaptation, looking into the viewing alley, and throwing a dart was repeated until 10 successful (scorable) throws were obtained for the particular subject in the particular situation. Occasionally, a dart either did not land on or stick into the floor of the throwing alley. Such a throw was not considered to be successful and was not scored.

Each of the 80 subjects was presented with each of the four situations, A, B, C, and D. A four-minute interval occurred between the end of the presentation of one situation and the beginning of another. The order in which the four situations were presented was varied between subjects. Since 24 orders were possible, these 24 orders were used three times (totaling 72 subjects), with four orders and their inverse selected again from the 24 possible orders, such that each situation (A, B, C, or D) was presented first equally often. Thus, of the 80 subjects, 20 were first presented with the reduced-cue situation A, 20 other subjects were first presented with B, 20 others with C, and 20 others with D.

Following the 10 scorable throws to the apparent distance of the card in a reduced-cue situation, the subject was asked to estimate the distance to the card in feet.

B. *The Full-Cue Situations*

1. *Apparatus*

For the full-cue situations, the fluorescent lights above the visual alley were turned on. There were no lights used in the throwing alley and the results of the dart throwing were not visible to the subject. The walls and floor of the visual alley were visible when the subject looked through the viewing aperture. A 38-inch-wide strip of brown paper was placed on the floor of the visual alley. Fastened to this strip of paper was a ladder pattern formed from a 1-inch-wide white tape. The sides of this pattern were separated by 28 inches, with the horizontal extensions occurring at 18-inch intervals. This pattern, part of which can be seen in Fig. 1, extended from the subject to a distance of 26.5 feet. A normal-sized seven-of-spades playing card (not a transparency) was mounted on a stand and placed at either 5, 10, 15, 20, or 25 feet from the subject. The normal-sized card located at each of these five distances constituted five full-cue situations. The bottom of the playing card was always at the height of the floor of the throwing alley. The subject binocularly observed the visual alley, in-

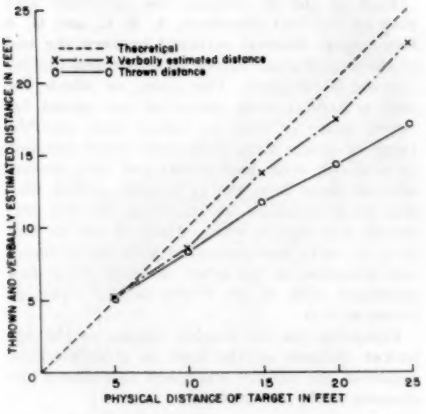

FIG. 2. Relation between physical and behavioral distance from all presentations of the full-cue situations.

cluding the playing card, through the viewing aperture. The light adaptation surface was not used in the full-cue situations.

2. *Procedure*

The same 80 subjects were used in the full-cue situations as had been used previously in the reduced-cue situations. The full-cue situations were always presented after the reduced-cue situations so that the subjects would be naive when they were first presented with the reduced-cue situations. Each subject completed 10 scorable dart throws to the apparent distance of the card in each of the full-cue situations. As in the reduced-cue situations, the task of the subject was carefully explained and he was reminded that the bottom of the card was at the height of the floor of the throwing alley. The shutter was closed over the viewing aperture between throws. A four-minute interval occurred between the end of one full-cue situation and the beginning of another. All five full-cue situations were presented to each subject, but the order in which the five full-cue situations were presented was different for each subject. Forty orders and their inverse were used. There were 16, 16, 17, 15, and 16 different subjects who were first presented with the target in the full-cue situations at 5, 10, 15, 20, and 25 feet respectively. For each subject, the time interval between the end of the last reduced-cue situation and the beginning of the first full-cue situation was 7 minutes. The experimental order for each subject throughout the entire experiment was specified by randomly pairing the order in which he was to see the reduced-cue situations with one of the 80 orders of presenting the full-cue situations.

Following 10 scorable throws to the apparent distance of the card in any full-cue situation, the subject was asked to estimate the distance to the card in feet.

III. RESULTS

A. *The Full-Cue Situations*

The results from the full-cue situations are presented first, since these results produced the calibration equations used in the analysis of the reduced-cue situations. The average throwing scores and verbal estimates from all presentations of the full-cue situations as a function of the physical distance of the playing card are shown in Fig. 2. The dotted line represents the results which would have been obtained if the throwing and verbal scores were the same as the physical distances of the playing card. Each thrown distance represented by a point on the ordinate of Fig. 2 is a mean of 80 scores, one from each subject, where each score is an average of 10 dart throws. Each verbal estimate represented by a point on the ordinate is a mean of 80 verbal estimates with one estimate from each of the 80 subjects. The graph involving the verbal estimates is closer to the dotted line than is the graph involving the thrown distance scores. However, the average of the between-subject standard deviations of the verbal estimates (12.9 feet) is larger than that from the throwing scores (2.1 feet). The average standard deviation of 12.9 feet is inflated by the verbal responses of one subject. When the verbal data of this subject are excluded, this standard deviation reduces to 4.2 feet. In order to estimate the precision with which the throwing method differentiated between target positions, standard errors of differences were computed for the differ-

ences between throwing scores when the targets were physically separated by five-foot intervals. Averaging the four resulting standard errors gave a value of .2 feet. This suggests that, in the full-cue situations, a distance difference of .3 feet could have been statistically differentiated by the dart-throwing at the .05 level of confidence (using the single-tailed *t* test).

B. *The Reduced-Cue Situations*

As was mentioned previously, the relation between thrown and visually perceived distance was determined from the results of the full-cue situations and was used to convert thrown distance to perceived distance in the reduced-cue situations. This was accomplished as follows: By the method of least squares a linear relation was calculated, for each subject, between the dart-throwing scores and the physical distance of the card in the full-cue situations. It was assumed that physical and perceived distance was equivalent in the full-cue situations. This resulted in a linear equation for each subject which expressed throwing distance as a function of perceived distance. This function is called the calibration equation for a subject. Each throwing score (a mean of 10 throws) from each subject in each reduced-cue situation was transformed by the calibration equation to a "perceived-distance score." Actually, the perceived-distance scores can be considered to represent a perceived absolute distance only if the perception of absolute distance occurred in the reduced-cue situations. If the perception of an absolute distance was absent in the reduced-cue situations, the throwing would be to an indifferent distance. However, in order to investigate whether the perception of absolute distance varied with changes in the retinal size of a familiar object, this transformation is logically to be preferred.

1. *First-Presented Reduced-Cue Situations*

As discussed in the introduction, in determining whether the retinal subtense of a familiar object is a cue to absolute distance, only one object should be visually present in the test situation, with similar objects of different retinal subtense being presented to different subjects. The results from each group of 20 subjects, who saw a particular reduced-cue situation first, meet both of these requirements. Therefore, the results from these first presentations of the reduced-cue situations were analyzed separately from the remaining results from the reduced-cue situations.

According to the size-distance hypothesis, the playing card in the reduced-cue situations A, B, C, and D should appear at 5, 10, 10, and 20 feet respectively. Let P_{A_1}, P_{B_1}, P_{C_1}, and P_{D_1} represent the perceived distance of the playing card in the first presentations of the reduced-cue situations A, B, C, and D. The subscript "1" refers to first presentations. The predictions from the size-distance hypothesis are that $P_{A_1} = 5$ feet, $P_{B_1} = 10$ feet, $P_{C_1} = 10$ feet, and $P_{D_1} = 20$ feet. A more general but less stringent hypothesis relating retinal size and perceived absolute distance is that $P_{A_1} < P_{B_1} = P_{C_1} < P_{D_1}$. If the results from this study do not support the latter hypothesis, they also do not support the former hypothesis. The analysis of the results will be mainly with respect to the latter, more general, hypothesis.

Table 1 gives the average results which were obtained from the first presentations of the reduced-cue situations. The entries in the column labeled "Thrown-Distance Score" are based upon

TABLE 1

RESULTS IN FEET FROM THE FIRST PRESENTATIONS OF THE REDUCED-CUE SITUATIONS ($N = 20$)

Reduced-Cue Situation	Thrown-Distance Score		Perceived-Distance Score		Verbal Report		Size-Distance Prediction	Physical Distance
	Mean	*SD*	Mean	*SD*	Mean	*SD*		
A	16.4	4.4	22.4	7.1	22.4	18.0	5	10
B	14.8	4.6	22.1	9.1	14.3	8.1	10	10
C	17.7	5.0	25.9	10.1	19.0	12.7	10	20
D	19.2	5.1	29.9	9.9	20.2	13.9	20	20

20 scores, with one score from each of 20 subjects, where each score is a mean of 10 throws of the darts. The entries in the column labeled "Perceived-Distance Score" were obtained by applying the appropriate calibration equations to the thrown-distance scores. The column labeled "Size-Distance Prediction" gives the distances at which the playing cards should have been seen according to the size-distance hypothesis. The column labeled "Physical Distance" gives the actual distances at which the playing cards were placed.

From Table 1 it appears that neither the thrown distances, the perceived distances, nor the verbally reported distances are in agreement with all the relationships involved in $P_{A_1} < P_{B_1} = P_{C_1} < P_{D_1}$. The statistical significance of the differences between the perceived-distance scores of Table 1 was determined by a simple analysis of variance.

TABLE 2

SUMMARY OF ANALYSIS OF VARIANCE OF THE PERCEIVED-DISTANCE SCORES FROM THE FIRST PRESENTATIONS OF THE REDUCED-CUE SITUATIONS

Source of Variance	*df*	Mean Square	*F*
Between Situations	3	248,968	3.22
Within Cells	76	77,346	
Total	79		

The results of this analysis are shown in Table 2. The obtained F is significant between the .05 and .01 level of confidence.

The significance of the differences between pairs of perceived distances P_{A_1}, P_{B_1}, P_{C_1}, and P_{D_1} were tested using the within-cells variance from the analysis of variance in calculating the error term. The results of these tests for single-tailed t probabilities are shown in Table 3. The direction of the subtractions in the column labeled "Test" was derived from

TABLE 3

SIGNIFICANCE OF THE DIFFERENCES BETWEEN PERCEIVED-DISTANCE SCORES FROM THE FIRST PRESENTATIONS OF THE REDUCED-CUE SITUATIONS

Test	Qualitative Differences	Difference in Feet	t	p* $df = 1/76$
1. $P_{B_1} - P_{A_1} > 0$	Angle	−.3	.10	Reversal
2. $P_{D_1} - P_{C_1} > 0$	Angle	4.0	1.38	—
3. $P_{C_1} - P_B > 0$	Distance	3.8	1.32	—
4. $P_{C_1} - P_{A_1} > 0$	Angle and Distance	3.5	1.23	—
5. $P_{D_1} - P_{B_1} > 0$	Angle and Distance	7.8	2.71	<.01
6. $P_D - P_{A_1} > 0$	Angle and Distance	7.5	2.61	<.01
7. $(P_{D_1} - P_{A_1}) - (P_{C_1} - P_{B_1}) > 0$	Angle Corrected for Distance	3.7	.91	—

* Single-tailed probability of occurrence.

the predictions of the size-distance hypothesis. The word "Reversal" in the column labeled "*p*" means that the obtained difference was opposite in direction to that predicted from this hypothesis. The column labeled "Qualitative Differences" in Table 3 indicates whether the playing cards in the two reduced-cue situations differed from each other in either or both angular (retinal) size and distance from the subject. It will be observed from test 1 and test 2 of Table 3 that, by itself, a decrease in the visual angle of the playing card did not produce a statistically significant increase in perceived distance. But, in 2 out of 3 cases, a decrease in visual angle accompanied by an increase in physical distance did produce a significant increase in perceived distance (see tests 4, 5, and 6). It is reasonable to expect that, in spite of the attempt to eliminate all distance cues except that of visual angle, some residual effect of other distance cues remained in the reduced-cue situations. This effect would be reflected in the results of test 3 in which the visual angle of the playing card was held constant but its physical distance was changed. As shown by the results of test 3, when the physical distance of the playing card was increased the perceived-distance score increased, but not by a statistically significant amount. Before concluding that the significant differences found in tests 5 and 6 can be attributed to the change in visual angle of the playing card, it must be demonstrated that these results cannot be attributed to the possible presence of other distance cues. For this reason, the difference found in test 3 was subtracted from the differences found in tests 5 and 6. Actually, the subtraction of the difference found in test 3 from that found in test 5 is unnecessary, since the resulting difference is the same as that from test 2. The subtraction of test 3 from test 6 is shown as test 7 in Table 3. It will be seen that the difference in test 7 was not significant at the .05 level of confidence. It can be concluded that the perceived-distance scores of Table 2 provide no evidence that the retinal subtense of the playing card was used as a cue to determine the perception of the absolute distance of the card.

An analysis of variance also was performed on the throwing scores of Table 1. The F value of this analysis was significant beyond the .05 level of confidence ($F = 3.07$). The significance of the differences between pairs of these throwing scores was tested by the procedure indicated in Table 3. The single-tailed probabilities resulting from the t tests were similar to those obtained from the analysis of the perceived-distance scores, with the only difference of any importance being that test 3 was significant beyond the .05 level of confidence ($t = 1.93$) when the throwing rather than the perceived-distance scores were used. Neither the throwing scores nor the perceived-distance scores offer support for the hypothesis that the retinal size of the familiar object was used as a cue to its absolute distance.

2. *All the Reduced-Cue Situations*

It will be recalled that the reduced-cue situations A, B, C, and D were each presented successively to each of the subjects. So far, the analysis of the data has been only with respect to the results from the *first* presentations of the reduced-cue situations. The average results from all presentations of each of the reduced-cue situations are given in Table 4. Each mean and standard deviation of Table 4 is based upon 80 scores, with one score from each of the same 80 subjects. The

TABLE 4

RESULTS IN FEET FROM ALL PRESENTATIONS OF THE REDUCED-CUE SITUATIONS ($N = 80$)

Reduced-Cue Situation	Thrown-Distance Score		Perceived-Distance Score		Verbal Report		Size-Distance Prediction	Physical Distance
	Mean	*SD*	Mean	*SD*	Mean	*SD*		
A	12.1	3.8	16.5	8.6	12.4	8.0	5	10
B	14.9	1.6	21.3	7.9	16.3	11.9	10	10
C	15.6	1.7	22.8	9.5	21.1	13.0	10	20
D	19.0	1.5	28.4	8.0	26.1	19.7	20	20

calibration equations were used to convert throwing scores to perceptual scores. An analysis of variance was performed on these perceived-distance scores with the results shown in Table 5. The *F* obtained for the main effect (situations A, B, C, and D) was significant beyond the .001 level of confidence. The results of the one-tailed *t* test of the significance of the differences between pairs of the perceived-distance scores of Table 5 are given in Table 6. It will be observed that all the differences in Table 6 are significant beyond at least the .025 level of confidence. The perceived-distance scores varied inversely with the retinal size of the playing card between successive presentations of the reduced-cue situations. As indicated by tests 1, 2, and 7 of Table 6, these results cannot be accounted for by the effect of distance cues other than changes in retinal size.

A parallel analysis was completed for the throwing scores of Table 4. The resulting *F* and *t* values were very similar to those which occurred with the perceived-distance scores in Tables 5 and 6. Both the throwing scores and the perceived-distance scores support the hypothesis that the visual angle of the playing card significantly modified the perceived-distance position of the card from one reduced-cue situation to another, when the same subjects were used in the several situations.

TABLE 5

SUMMARY OF ANALYSIS OF VARIANCE OF THE PERCEIVED-DISTANCE SCORES FROM ALL PRESENTATIONS OF THE REDUCED-CUE SITUATIONS

Source of Variance	*df*	Mean Square	*F*
Between Situations	3	1,775,177	81.47
Between Subjects	79	215,149	9.87
Situations × Subjects	237	21,789	
Total	319		

TABLE 6

SIGNIFICANCE OF THE DIFFERENCES BETWEEN PERCEIVED-DISTANCE SCORES FROM ALL PRESENTATIONS OF THE REDUCED-CUE SITUATIONS

Test	Qualitative Differences	Difference in Feet	*t*	p^a $df = 1/237$
1. $P_B - P_A > 0$	Angle	4.8	6.24	$< .01$
2. $P_D - P_C > 0$	Angle	5.6	7.29	$< .01$
3. $P_C - P_B > 0$	Distance	1.5	1.96	$< .025$
4. $P_C - P_A > 0$	Angle and Distance	6.3	8.20	$< .01$
5. $P_D - P_B > 0$	Angle and Distance	7.1	9.27	$< .01$
6. $P_D - P_A > 0$	Angle and Distance	11.9	15.50	$< .01$
7. $(P_D - P_A) - (P_C - P_B) > 0$	Angle Corrected for Distance	10.4	9.57	$< .01$

[a] Single-tailed probability of occurrence.

The analysis of the results from the *first*-presented reduced-cue situations (Tables 2 and 3) gave no indication that absolute-distance perception had occurred as a function of the retinal size of the playing card. The analysis did suggest, however, that some perception of absolute distance had occurred as a function of distance cues other than those of retinal size. These cues would operate to make the physical and apparent distances of the playing cards coincide. The degree to which the physical and apparent distances are not in agreement indicates the extent to which these residual cues of absolute physical distance were unimportant in producing perceptions of absolute distance in the reduced-cue situations. This can be evaluated by comparing the perceived-distance scores of Table 1 with the actual physical distances of the cards. It will be observed from Table 1 that, when the cards were at 10 feet, the perceived-distance scores were greater than 20 feet. That the perceived-distance scores are not proportional to the physical distances in the first presentations of the reduced-cue situations is also suggested by Table 1. Computing the ratio of the largest to the smallest perceived-distance score in Table 1 gives a value of 1.4. The corresponding ratio of the physical distances is 2.0. It may be concluded that the residual cues to the physical distance of the playing cards were not very effective in producing perceived absolute distance in the reduced-cue situations. The perception of absolute distance in the reduced-cue situations will be regarded as having been largely indefinite. Consequently, it will be considered that the subject threw to what was essentially an indifferent distance when *first* presented with a reduced-cue situation. This throwing distance was not indifferent, however, in that a throwing force was used which was definite, and which probably was peculiar to the particular subject. Later, the same subject, upon being presented with a second reduced-cue situation, modified the throwing force depending upon whether the card in the second presentation appeared to be more or less distant than that in the first presentation. Consider the case in which a subject was presented with the reduced-cue situations in the order A_1 B_2 C_3 D_4, where the subscripts refer to the order of presentation. Upon being presented with A_1, the darts would be thrown to some indifferent distance. When the same subject was presented with B_2, he behaved as though he remembered both the retinal subtense of A_1, in relation to that of B_2, and the force of the throwing he had used in A_1. Since the card in B_2 was retinally smaller than that in A_1, the card in B_2 was judged to be more distant than the previously indefinitely perceived distance of the card in A_1, and the force of the throwing was increased. The throwing on C_3 and D_4 for the same subject would be determined in a similar manner. For the order of presentation A_1 B_2 C_3 D_4, the relative magnitude of the throwing would be $T_{A_1} < T_{B_2} = T_{C_3} < T_{D_4}$. *Since the perception of an absolute distance as a function of retinal subtense was not demonstrated by the analysis of the results from the first-presented reduced-cue situations, the perception of distance which occurred between successively presented reduced-cue situations as a function of retinal subtense is considered to be relative-distance perception.* The results indicate that relative-distance perception, as some function of relative retinal subtense, occurred between the successively presented reduced-cue situations.

If relative-distance perception occurred as a function of the relative retinal subtense of the playing cards, it would be expected that the order of magnitude of the throwing scores (or perceptual scores) in the successively presented reduced-cue situations would be independent of the order of presentation. This can be demonstrated by considering the case in which a subject was successively presented with the reduced-cue situations in the order D_1 C_2 B_3 A_4. After making a perceptually indifferent throwing score on D_1, the subject, when presented with C_2, should produce a throwing score which was less than that which resulted from D_1. This would be a consequence of the retinal subtense of the card in C_2 being greater than that of the card in D_1. Similarly, A_4 should have the smallest throwing score of the four situations. The relative magnitude of the throwing scores would be $T_{A_4} < T_{B_3} = T_{C_2} < T_{D_1}$. As discussed above, this is the same order of relative magnitude of throwing scores which would be expected from the order of presentation A_1 B_2 C_3 D_4. Continuing this, it will be seen that the order of magnitude of the throwing (or perceptual scores) would be independent of the order of presentation of the reduced-cue situations. It is this expectation which, in the comparative absence of absolute-distance perception in the first-presented situations, permits the analysis of the results from all the presentations of the reduced-cue situations to be interpreted.

3. *The Independence of Absolute- and Relative-Distance Perception*

In the introduction, it was suggested that the characteristic which discriminates between apparent absolute and apparent relative distance is the reference point with respect to which the perception occurs. This reference point is some function of the position of the observer for absolute-distance perception, but is independent of the position of the observer for relative-distance perception. It has been pointed out that experimental results which have been attributed to an absolute-distance perception might be explained by a relative-distance perception. Conversely, the difference between two absolute-distance perceptions might be considered, mistakenly, to be a perception of relative distance, even though the perceptual reference point in this case was not independent of the position of the observer. The results from the reduced-cue situations do not support the hypothesis that perceived absolute distance occurred in the reduced-cue situations as a function of the retinal size of the playing card. But the results do indicate that relative-distance perception occurred as a consequence of changes in retinal size. This suggests that, as a function of retinal size, relative-distance perceptions might have occurred in the reduced-cue situations without a concomitant occurrence of absolute-distance perceptions. This offers the possibility that an apparent relative distance between two objects can occur independently of the perception of the distance of either of these objects. Thus, the definition of relative-distance perception used in this study may parallel a real perceptual ability. A test of this possibility would be a test in which an affirmative answer simultaneously would depend upon the absence of perceived absolute distance and the presence of perceived relative distance.

While the order of magnitude of the perceptual (or throwing) scores should

be independent of the sequence of presentation of the reduced-cue situations, this is not the case with the absolute magnitude of the perceptual (or throwing) scores. Consider, for example, the sequence of presentation A_1 B_2 as compared with the sequence of presentation D_1 B_2 and assume, for the moment, that all distance cues except that of retinal size had been completely eliminated. Under the condition that no absolute-distance perception occurred in the reduced-cue situations, P_{A_1} and P_{D_1} should not differ significantly from each other. With the sequence A_1 B_2, P_{B_2} as a consequence of the smaller retinal size in B_2 than in A_1 should be greater than P_{A_1}. With the sequence D_1 B_2, P_{B_2} should be less than P_{D_1}. Therefore, P_{B_2} with the sequence of presentation A_1 B_2 should be greater than P_{B_2} with the sequence D_1 B_2. This is based upon the assumptions that (*a*) absolute-distance perception did not occur with A_1 and D_1, but (*b*) relative-distance perception occurred between successively presented situations. Similarly, P_{C_2} with the sequence of presentation A_1 C_2 should be greater than P_{C_2} with the sequence D_1 C_2. Both B_2 and C_2 should have resulted in larger scores when preceded by A than by D.

Actually, as shown in Table 3, test 6, P_{D_1} was significantly larger than P_{A_1}. This is attributed to the effect of residual cues of absolute distance, other than the cue of retinal size. To the extent that these cues to the physical distance of the target in either A and D or B and C were present, B_2 and C_2 should not have resulted in larger scores when preceded by A_1 than by D_1. Larger scores in B_2 and C_2, as a consequence of being preceded by A_1 rather than by D_1, indicate that relative retinal size can produce a perception of the relative distance between two objects, which is independent of a perception of the absolute distance of either.

TABLE 7

AVERAGE PERCEPTUAL SCORES IN FEET FROM SITUATIONS B_2 AND C_2, DEPENDING UPON WHETHER THE PRECEDING SITUATION WAS A_1 OR D_1

Prior Situations	Results from B_2		Results from C_2	
	Mean	*SD*	Mean	*SD*
A_1	25.6	7.6	26.6	6.1
D_1	17.2	9.7	19.2	6.1
Difference	8.4		7.4	
Average Difference	7.9			

In this study there were seven subjects who had the sequence A_1 B_2; seven who had the sequence D_1 B_2; seven who had the sequence A_1 C_2; and seven who had the sequence D_1 C_2. Table 7 gives the average perceptual scores from B_2 and C_2, depending upon whether the preceding situation was A_1 or D_1. The average difference of 7.9 feet is the difference between the mean of 14 scores on B_2 or C_2, when the preceding situation was A_1, and the mean of 14 scores on B_2 or C_2, when the preceding situation was D_1. It is the average amount by which the perceptual scores from B_2 and C_2 were larger as a consequence of being preceded by A_1 rather than by D_1. This average difference was significant beyond the .01 level of confidence ($t = 2.66$, $df = 26$) with the single-tailed t test. This indicates that the presence of relative-distance perception as a function of the size of a familiar object can occur independently of the occurrence of absolute-distance perception.

IV. Discussion

A. *The Full-Cue Situations*

It is reasonable to expect the perception of absolute distance to occur in the full-cue situa-

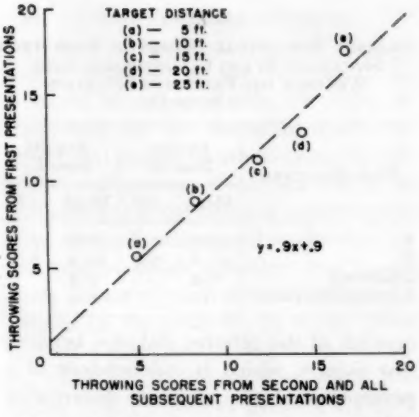

FIG. 3. Relation between the mean throwing scores in feet from the first and all subsequent presentations of the full-cue situations.

tions. It can be demonstrated that, unlike the results from the first presentations of the reduced-cue situations, the throwing in the first presentations of the full-cue situations was not largely indifferent. This can be demonstrated by comparing the average throwing scores from the first presentations of the full-cue situations with the average throwing scores from the remaining presentations of the full-cue situations. This is shown in Fig. 3 where this relationship is plotted for the five distances of the playing card. It will be seen that the data reasonably fit a straight line. A straight line was fitted to these data by the method of least squares. The equation of this line is given in Fig. 3. The similarity of this equation to the equation $y = x$ indicates that the throwing scores in the first and remaining presentations of the full-cue situations were essentially the same.

B. *Experimental Precision*

This study produced no evidence that any relation occurred between the retinal size of the familiar object and the perception of absolute distance. But it cannot be concluded that no such relation existed, since this conclusion would require the acceptance of the null hypothesis. This raises the problem of the experimental precision with which the relation between perceived absolute distance and the retinal size of a familiar object has been investigated. This experimental precision can be considered either from the standard errors involved in the study, or from the kind of perceptual discriminations which the study was able to demonstrate.

One possible estimate of experimental precision is the error term which was used to test the statistical significance of the average score difference between first presentations of the reduced-cue situations. This error term of 2.9 feet would suggest that a perceived difference between situations of 4.8 feet (1.645×2.9 feet) would have to occur before a statistically significant mean difference would be present with the one-tailed t test. On rational grounds, however, this is not a good estimate of the experimental precision with which familiar size was tested as a cue to absolute distance. The error term from the first-presented reduced-cue situations would vary depending upon the precision with which the perception of absolute distance occurred. For example, with no perception of absolute distance, the variability between throwing scores from the first presentations of the reduced-cue situations would be large, since the throwing would not be controlled by a visually perceived distance. The problem is to determine an error term which reflects the precision of measurement which would occur if the perception of absolute distance were definite in the reduced-cue situations. In the full-cue situations it was assumed that the perception of absolute distance was accurate. The standard error, calculated from the average between-subject variability in the full-cue situations, is a possible measure of the precision with which the existence of a relation between perceived absolute distance and retinal size was tested in the reduced-cue situations. This was calculated by computing the standard deviation of the subjects' scores in each of the full-cue situations, for each of the four groups of 20 subjects who had previously been used in the first presentations of the reduced-cue situations. The resulting average standard deviation was 2.0 feet. Using this average standard deviation, the standard error of the mean difference between the results from different groups of 20 subjects is .7 feet. With this standard error, a mean difference of 1.1 feet would be significant at the .05 level of confidence, with the one-tailed t test. This indicates that with two different groups of 20 subjects, with each group presented with a different reduced-cue situation, a mean difference between groups of 1.1 feet in perceived absolute distance would be significantly differentiated by the throwing procedure at the .05 level of confidence. As noted previously, the error term calculated from the reduced-cue situations is probably too large to be considered an estimate of the precision with which the relation between the retinal size of a familiar object and perceived absolute distance was tested. The estimate from the full-cue situations, however, is possibly too small for this purpose, since it contains the assumption that, if the perception of absolute distance occurred

in the reduced-cue situations, the variability between subjects attributable to this perception would be no greater than the variability which occurred in the full-cue situations. To the degree that additional perceptual variability can be tolerated without rejecting the possibility of some general relation between retinal size and perceived absolute distance, this estimate of experimental precision is too small. Therefore, the experimental precision with which the occurrence of the relation between the retinal size of a familiar object and perceived absolute distance was tested lies somewhere between these two possible estimates, i.e., somewhere within the range of approximately 1 to 5 feet.

It is possible to consider conclusions which reject the null hypothesis with respect to any particular relation between retinal size and the perception of absolute distance. One such relation is that given by the size-distance hypothesis. The perceived distances predicted from the size-distance hypothesis for the reduced-cue situations are given in Table 1. The perceptual scores of Table 1 are logically the values to compare with the corresponding predicted distances. The error term from the analysis of variance of these perceived distance scores (2.9 feet) can be used to calculate the standard error, and thus the statistical significance of the differences between the perceptual scores and the corresponding predicted scores. If this is done, it is found that all of these differences are significant beyond the .01 level of confidence, by the double-tailed *t* test. This supports the conclusion that the magnitudes of the obtained perceptual scores are not in agreement with the values predicted from the size-distance hypothesis.

Any statistical significance which occurred between the average results of the reduced-cue situations is evidence that the throwing method can measure perceived depth in these situations. Statistical significance was present between the average results from the successively presented reduced-cue situations, indicating the occurrence of relative-distance perception. The standard error used to test the significance of the mean difference between any two such situations was .8 feet for the perceived-distance scores. This is much smaller than the corresponding error term of 2.9 feet from the perceived-distance scores with the *first*-presented reduced-cue situations. The experimental precision of the test for relative-distance perception was greater than that for absolute-distance perception. But it was also found that the perceived-distance score from situation B or C varied, depending upon whether B or C was preceded by A or D (see Table 7). The standard error for the test of significance of this comparison was 3.0 feet. This is of the same order of magnitude as the standard error of pairs of mean differences from the first-presented reduced-cue situations (2.9 feet). This indicates that, with standard errors of this magnitude, a statistically significant mean difference can appear, when the basis for expecting this difference is that relative—but not absolute—distance perception is some function of the retinal size of familiar objects.

C. *Perception of Distance*

The first time a reduced-cue situation was presented to a subject, the situation was a unique presentation in that the subject probably had never previously encountered a situation identical to it. But the subject had encountered normal-sized playing cards prior to the experiment. (This prior experience is obviously necessary in order for the playing card to be a familiar object.) Since these prior experiential situations were usually full-cue situations, the absolute distance of the object was undoubtedly perceived. It might be expected that, upon being presented with a particular retinal subtense of a playing card in a reduced-cue situation, the subject would make a distance judgment relative to this prior experience. If such a result had been demonstrated, it would have been difficult to decide whether the distance judgment should be termed absolute or relative. Perhaps the reason that such a result did not appear in this study is that too long an average time interval occurred between the prior experience and the experiment. It will be recalled that, with the relative localization demonstrated in the reduced-cue situations, only a four-minute interval separated the successive presentations.

This emphasizes the difficulty in demonstrating absolute-distance perception without the possibility that relative-distance perception had produced the results. But, as has been indicated by this study, a relative-distance perception as a function of relative retinal size can occur independently of the occurrence of absolute-distance perception.

This study does not suggest that retinal size has no part in the perception of absolute distance. In many situations, the perception of absolute distance may at least partially consist of a series of successive relative-distance perceptions. In this sense, a series of relative retinal sizes may be a significant factor in determining the perception of absolute distance. Also, there is no evidence that, given the proper training, the subjects could not have learned to use the absolute retinal size of a familiar object as a cue to determine its absolute distance. But, a distinction can be made between an immediate distance perception and an inferential estimate of distance (2, p. 342). Therefore, whether such learning would result in the ability to make an inferential estimate of absolute distance or would

produce an absolute-distance perception would remain to be investigated.

V. Summary and Conclusions

An experiment was conducted to determine whether the retinal subtense of a familiar object could act as a determiner of its apparent absolute distance. To test this question, it was required that each subject be presented with only one object in an otherwise homogeneous field, and that different subjects be used with the different retinal sizes of the same familiar object. Apparent distance was measured by having the subjects throw darts to the apparent distance-position of a playing card. Neither the trajectory, nor the place of impact of the darts was visible to the subjects. Two kinds of situations were used. In one, called the reduced-cue situations, the purpose was to eliminate all distance cues but retinal size. In the other, called the full-cue situations, a variety of distance cues were present. The results from the full-cue situations were used to change throwing scores from the reduced-cue situations to perceived-distance scores. The analysis of the average differences in the scores between the *first* presentations of different reduced-cue situations revealed no evidence for the presence of absolute-distance perception as a function of retinal size. However, between the *successively* presented reduced-cue situations, a change in the magnitude of the scores as a consequence of a change in retinal size did occur. This was interpreted to be the result of relative- not absolute-distance perception. It seems that relative-distance perception as a function of the relative size of familiar objects can occur without the concomitant occurrence of absolute-distance perception.

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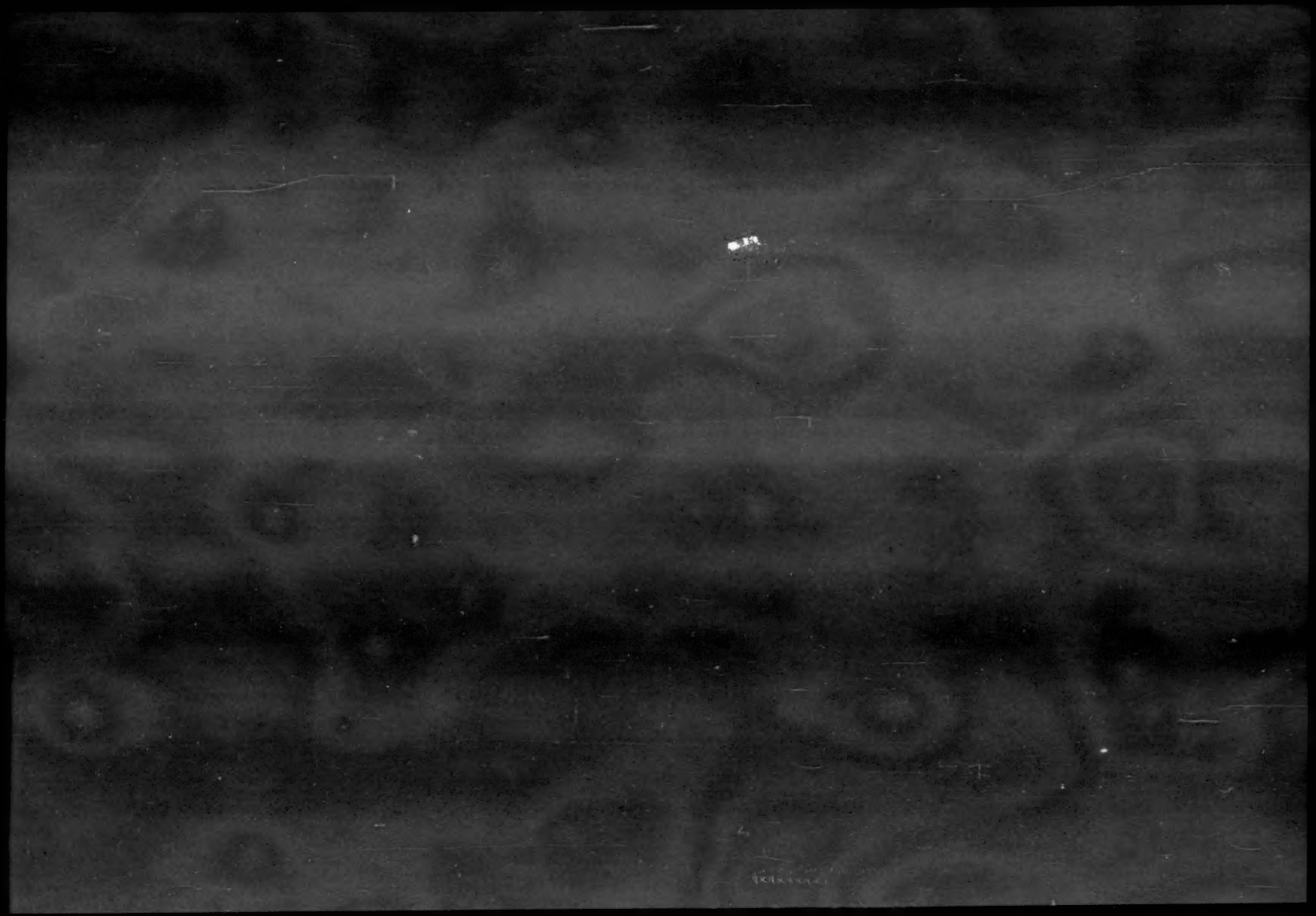
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